ERDC/EL TR-01-35

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20011231 138

Evaluation of Manufactured Soil Using Dredged Material from New York/New Jersey Harbor Newton Creek Site

Phase 1: Greenhouse Bench-Scale Test

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October 2001

ERDC/EL TR-01-35
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Final report

Prepared for U.S. Army Engineer District, New York
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Preface

This report describes work performed by the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. This study was sponsored by the U.S. Army Corps of Engineers District, New York, under a civil works reimbursable project and U.S. Environmental Protection Agency NY/NJ Harbor dredged material decontamination technologies demonstration project under Section 405, Water Resources Development Act of 1992.

The study was conducted and the report prepared by Drs. Thomas C. Sturgis and Charles R. Lee, Fate and Effects Branch (FEB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL). Messrs. Henry C. Banks, Jr., and Kervin Johnson, AScI Corporation, provided assistance in preparing and conducting the laboratory/greenhouse screening tests. Mr. Michael R. Burchell II, graduate student, North Carolina State University, Raleigh, provided technical assistance with the Metcalf and Eddy treated dredged material product.

The study was conducted under the direct supervision of Dr. Bobby L. Folsom, Jr., Chief, FEB, and under the general supervision of Dr. Richard E. Price, Chief, EPED, and Dr. Edwin A. Theriot, Acting Director, EL.

At the time of publication of this report, Dr. James R. Houston was Director of the ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

This report should be cited as follows:

> Sturgis, T. C., Lee, C. R., Banks, H. C., Jr., Burchell, M. R., II, and Johnson, K. (2001). "Evaluation of manufactured soil using dredged material from New York/New Jersey Harbor Newton Creek Site; Phase 1: Greenhouse bench-scale test," ERDC/EL TR-01-35, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Executive Summary

Recycling of waste materials within the environment must be a serious national goal in order for the United States to manage its resources wisely. The U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, has established Cooperative Research and Development Agreements (CRDAs) to develop technology for the manufacture of topsoil using sediment/dredged material (decontaminated and contaminated), cellulose waste materials, and nutrient-rich organic waste materials. The recycled soil manufacturing technology would allow the development of fertile topsoil that could be used in a beneficial, productive, and environmentally sound manner. In addition, the manufactured topsoil technology would provide an alternative to conventional disposal of the nation's waste/resource materials (e.g., in landfills or confined placement facilities (CPFs)). Bench-scale screening tests (seed germination and plant growth) were used in Phase 1 of an investigation to evaluate the feasibility of using treated dredged material from the Metcalf and Eddy process (decontaminated New York/New Jersey (NY/NJ) Harbor dredged material via solvent extraction) and untreated dredged material collected directly from the NY/NJ Harbor Newton Creek Site. Screening tests included proprietary blends with a range of dredged material content, a range of cellulose, and BIONSOIL™ biosolids.

a. *Seed germination screening test.* Tomato, marigold, vinca, and ryegrass were tested following procedures developed by a nationally known bagged soil products company. Seed germination was highest in proprietary Blend 5 consisting of NY/NJ Harbor dredged material, cellulose, and BIONSOIL™ biosolids. The lowest seed germination was observed in proprietary Blend 1, consisting of dredged material only. Seed germination in proprietary blends using Metcalf and Eddy treated NY/NJ Harbor dredged material was significantly lower than seed germination in proprietary Blend 5 using the untreated NY/NJ Harbor dredged material.

b. *Extended plant growth test using manufactured topsoil mixtures.* A 7-week plant growth test was conducted using the same experimental design as the seed germination study. Visual observation of leaf color, size, and shape and total aboveground biomass was used to evaluate the influence of the different manufactured topsoil blends on plant growth. Results showed that the highest biomass was

obtained from proprietary Blend 5 in both tests. Therefore, Blend 5, consisting of NY/NJ Harbor dredged material blended with cellulose and BIONSOIL™ biosolids, looks very promising as a manufactured topsoil product. Chemical analyses showed that considerably lower levels of organic and inorganic chemicals were measured in proprietary Blend 5 with cellulose and BIONSOIL™ biosolids than in the original NY/NJ Harbor dredged material. These analyses also showed that leaching of organic compounds and metals from this blend was negligible.

Manufactured topsoil blends prepared with treated/decontaminated dredged material from the Metcalf and Eddy process were not very productive. Ryegrass did not grow in blends using a cement-amended decontaminated NY/NJ Harbor dredged material. However, some plant growth did occur in the non-cement decontaminated NY/NJ Harbor dredged material, but ryegrass biomass production was considerably lower than that in proprietary Blend 5 consisting of the untreated NY/NJ Harbor dredged material. Therefore, decontaminated dredged material produced from the Metcalf and Eddy solvent extraction process should not be considered for use in fertile manufactured topsoil products.

In summary, Phase 1 testing indicated that topsoil can be manufactured from NY/NJ Harbor dredged material blended with cellulose and BIONSOIL™ biosolids according to a patented formula. The amount of dredged material blended in the topsoil will determine the salt content of the resultant topsoil. This Phase 1 research determined the maximum amount of dredged material that can be used to keep the salt low enough to grow grass. Contaminant concentrations were also reduced after blending with cellulose and BIONSOIL™ biosolids. Dioxin TEQs in the manufactured soil was measured at 182 pptr as total content and 0.629 pptr as TCLP leachable in proprietary Blend 5.

Plant growth was reduced but appeared to be adequate for controlling soil erosion. Grass did not take up pesticides and PAHs and only took up small amounts of PCBs (~15 ppb) and dioxin (6.45 pptr TEQs). Grass tissue metals were not elevated except for cadmium (2.63 ppm). Manufactured topsoil concentrations of cadmium ranged from 7.9 to 11.3 ppm. Grass uptake of cadmium can be controlled by using plant species that are known not to take up cadmium and other metals. This phytoremediation approach was included in the Phase 2 pilot-scale field demonstration at Port Newark and will be evaluated in the Phase 3 large-scale field demonstration at a landfill and an abandoned coal mine site. Two other phytoremediation approaches to degrade organic contaminants such as PAHs, PCBs, and dioxin and to extract metals from the manufactured topsoil were also included in the Phase 2 pilot-scale field demonstration at Port Newark and will be further evaluated in the Phase 3 large-scale field demonstration.

1 Introduction

Background

The U.S. Army Corps of Engineers (USACE) New York District is responsible for maintaining navigation in New York/New Jersey (NY/NJ) Harbor. This task requires the removal of approximately 2-5 million cu yd of dredged material each year. Approximately 75 percent of that volume does not pass stringent ocean-disposal testing criteria and, therefore, requires restricted disposal alternatives. This material contains a wide range and different levels of contaminants, including PAHs, PCBs, pesticides, and metals. Consequently, the New York District is evaluating technologies that will destroy/immobilize toxic chemicals in the dredged material so it can be used in a more beneficial manner. The U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, was asked to evaluate the potential to manufacture topsoil from untreated and treated (decontaminated) NY/NJ Harbor dredged material. To accomplish this task, ERDC Environmental Laboratory conducted manufactured soil screening tests, using its cooperative research and development agreements (CRDAs) with Paul Adam (Terraforms), BION Technologies, Inc., N-Viro International, Inc., and Scott and Sons Company.

The CRDA allowed ERDC to use BIONSOIL™ biosolids, a patented formulation developed by BION Technologies, Inc., as an ingredient of the Recycled Soil Manufacturing Technology (formerly Terraforms) to manufacture topsoil from dredged material. CRDAs that have been established or are pending will enable the Recycled Soil Manufacturing Technology to be developed and demonstrated at USACE confined placement sites. They are listed in the following tabulation:

Cooperating Company	Aspect of Manufactured Soil
BION Technologies, Inc.[1]	Reconditioned biosolids from cow manure
Recycled Soil Manufacturing Technology (RSMT) (formerly Terraforms)	Formulation and blending equipment
N-Viro International	Reconditioned biosolids from sewage sludge
Scott and Sons Company[1]	Bagged soil products

[1] Pending.

The recycled soil manufacturing technology is site specific. The optimal blend for a specific dredged material will depend on the physical and chemical characteristics of that dredged material and the available cellulose and biosolids. The proprietary blend found productive for one site may not be similar to dredged material, cellulose, and biosolids from other sites. Therefore, bench-scale tests and demonstrations (pilot-scale and large-scale) should be conducted on each individual dredged material. Following successful demonstration of the recycled soil manufacturing technology, commercialization of the technology would be developed by the CRDA partners and local interests. Proprietary restrictions are placed on describing the nature and amount of each ingredient that makes up the blend; therefore, implementation and application of the recycled soil manufacturing technology will require appropriate licensing from the patent holder, Mr. Paul Adam.

Purpose and Scope

The purpose of this report is to present the results of manufactured topsoil screening tests conducted by the ERDC, Vicksburg, MS. These screening tests determined the feasibility of using dredged material from NY/NJ Harbor in the recycled soil manufacturing technology. The best formulation of dredged material, cellulose, and BIONSOIL™ biosolids was determined and recommended for field demonstration at NY/NJ Harbor.

2 Materials and Methods

Collection of Dredged Material

The dredged material used in this study was collected from the NY/NJ Harbor Newton Creek Site located along the boroughs of Queens and Brooklyn in New York City. The dredged material was collected and placed into a 1892.5-liter (500-gal) tank. The dredged material was thoroughly mixed in the field using a Lightnin™ model XJ-350 portable impeller agitator. After mixing, the dredged material was then placed in four 37.85-liter (30-gal) plastic drums and shipped to the ERDC, Vicksburg, MS. Upon arrival at the ERDC, the dredged material was stored at 4 °C until greenhouse/laboratory testing. Subsamples of the dredged material were used for chemical and physical characterization.

Manufactured Topsoil Screening Tests, Seed Germination and Plant Growth

New York/New Jersey Test 1

Manufactured topsoil screening tests (seed germination and plant growth) using the procedures of a national bagged soil product company were used to evaluate the feasibility of manufacturing soil from NY/NJ Harbor dredged material for beneficial use as cover for superfund sites, mining sites, and landfills. These tests included various blends of dredged material, cellulose, and BIONSOIL™ biosolids (reconditioned dairy cow manure). A specific blend was prepared by placing an appropriate amount of cellulose and BIONSOIL™ biosolids in a V-mixer and mixing for 5 min. NY/NJ Harbor dredged material was then added and mixed an additional 5 min. This process was repeated until all blends were prepared.

Tomato, vinca, marigold, and ryegrass (four annual plant species) were grown from seed in the various blends to evaluate seed germination and plant growth. These plants are sensitive to salt, metals, and nutrient imbalances and represent a wide spectrum of upland plants. Tomato, marigold,

and vinca seeds were obtained from Ball Seed Co., Chicago, IL, and shipped to ERDC, Vicksburg, MS. Ryegrass seed was purchased from Warrenton Farm and Garden Center, Vicksburg, MS. *Cyperus esculentus,* a wetland plant, was added to the test to evaluate growth of a more salt-tolerant plant species. *Cyperus esculentus* was grown from tubers and was purchased from Wildlife Nurseries, Inc., in Oshkosh, WI. Wetland creation has been achieved with estuarine dredged material (e.g., the Field Verification Program (FVP)). However, one normally does not create a wetland with highly contaminated dredged materials because of the potential exposure of wetland plants and animals to the contaminants.

Five 4.2-cm × 8.22-cm × 1.02-cm plastic trays lined with a sheet of plastic were used for seed germination tests. Each blend was added separately to each tray to a depth of approximately 5.08 cm (2 in.). Three rows of 10 tomato seeds, 10 vinca seeds, 10 marigold seeds, and 20 ryegrass seeds were planted in the same tray containing each manufactured soil blend. All trays were watered when necessary, and seeds were allowed to germinate in the greenhouse under lights providing a day length of 16 hr. The temperature in the greenhouse was maintained at 32.2 ± -5 °C during the day and 21.1 ± -5 °C at night. Emerged seedlings were counted after 14 and 21 days to determine mean germination percentages.

A 7-week growth test, using manufactured soil blends similar to those used in the seed germination test, was conducted concurrently with the seed germination test. Ninety-six 10-cm (4-in.) pots with 10-cm (4-in.) saucers were used to evaluate the growth and appearance of the developing plants in the different blends. All 10-cm (4-in.) pots were prepared by placing a number 42 Whatman™ filter paper in the bottom of each pot to prevent the loss of soil. Each blend was then added separately to each prepared 10-cm (4-in.) pot to approximately 1.27 cm (0.5 in.) from the rim. Seeds were added separately to each blend: 3 tomato seeds, 3 marigold seeds, 3 vinca seeds, and 20 ryegrass seeds.

All the pots were randomly placed on tables in the greenhouse under lights providing a day length of 16 hr. Lights were arranged in a pattern alternating a high-pressure sodium lamp and a high-pressure multi-vapor halide lamp which provided an even photosynthetic active radiation (PAR) distribution pattern of 1200 *u*Einsteins/m^2/sec. The temperature in the greenhouse was maintained at 32.2 ± 5 °C during the day and 21.1 ± 5 °C at night. Relative humidity was maintained as close to 100 percent as possible, but never less than 50 percent.

Plants, except for the ryegrass, were thinned to one plant per pot when more than one seed germinated in a pot. Where no seeds germinated in pots, plant seedlings were removed from the germination trays or another 10-cm (4-in.) pot having more than one plant and transplanted to the pot of a corresponding manufactured soil blend. Plant seedlings were then allowed to grow and develop to evaluate plant growth and appearance. After 7 weeks, plants were observed, photographed, and harvested from the various blends. The plant material was cut and washed in deionized water to

remove any soil particles and then blotted to remove excess water. The plant material was bagged, weighed, dried, and reweighed to determine fresh and dry biomass. Plant material was also separated for organic and inorganic chemical analysis. Table 1 shows the experimental design used in the first soil screening test.

Table 1
Experimental Design for NY/NJ Harbor Manufactured Topsoil Screening Test 1

Treatments
Blend 1 NY/NJ Harbor dredged material Blend 2 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids Blend 3 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids Blend 4 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids Blend 5 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids Blend 6 Fertile reference control
Plant Species
1. *Lycopersicon esculentum* (Tomato - Big Boy) 2. *Tagetes patula* (Marigold) 3. *Lolium multiflorum Lam* (Ryegrass - Gulf Annual) 4. *Catharanthus roseus* (Vinca) 5. *Cyperus esculentus* (Yellow nutsedge)
Experimental Design
Seed Germination Test 6 treatments x 4 species split-plots design with 3 replicates, 6 flats x 4 species x 3 replicates **Growth Test** 6 treatments x 4 species x 4 replicates completely randomized block design 6 x 4 x 4 = 96 experimental units (4-in. planting pots).

New York/New Jersey Test 2

A second screening test was started to evaluate the effect of increasing the percentage of BIONSOIL™ biosolids on seed germination and plant growth. Plant seedlings were removed from the trays containing the various blends used in the first seed germination test. Then, an additional predetermined percentage of BIONSOIL™ biosolids was added directly to the trays and thoroughly mixed. All trays were then reseeded with tomato, vinca, marigold, and ryegrass. Emerged seedlings were counted after 14 and 21 days to determine seed germination percentages. The procedures and greenhouse setup were similar to the first seed germination test.

After removing below-ground plant parts from all pots containing the various blends used in the first plant growth test, a predetermined volume percentage of BIONSOIL™ biosolids was amended directly to the pots. All pots were thoroughly mixed. The percentage of BIONSOIL™ biosolids was corrected. The additional BIONSOIL™ biosolids lowered the overall amounts of each ingredient. Therefore, the percentage of each ingredient was lower in Test 2 than in Test 1. An additional blend (**new**) consisting of fresh NY/NJ dredged material, cellulose, and BIONSOIL™

biosolids was added to the experimental design (Table 2). The blend designated as **new** was prepared using procedures previously described. The greenhouse setup and procedures were similar to those of the first growth test. The experimental design is shown in Table 2.

Table 2
Experimental Design for NY/NJ Harbor Manufactured Topsoil Screening Test 2

Treatments
Blend 1 NY/NJ Harbor dredged material
Blend 2 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 3 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 4 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 5 NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 6 **(new)** NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 7 Fertile reference control
Plant Species
1. *Lycopersicon esculentum* (Tomato - Big Boy)
2. *Tagetes patula* (Marigold)
3. *Lolium multiflorum Lam* (Ryegrass - Gulf Annual)
4. *Catharanthus roseus* (Vinca)
5. *Cyperus esculentus* (Yellow nutsedge)
Experimental Design
Seed Germination Test
7 treatments x 4 species split-plots design with 3 replicates,
7 flats x 4 species x 3 replicates
Growth Test
7 treatments x 4 species x 4 replicates completely randomized block design
7 x 4 x 4 = 112 experimental units (4-in. planting pots).

New York/New Jersey Test 3

A third screening test was started to evaluate Metcalf and Eddy's treated/decontaminated NY/NJ dredged material for potential use as ingredients in manufactured soil products. Two products were tested, ORG-X (solvent extracted) and ORG-X + cement (organic solvent extracted and solidification/stabilization using portland cement). Eighty 10-cm (4-in.) pots with 10-cm (4-in.) saucers were used to evaluate seed germination and plant growth. All 10-cm pots were prepared by placing a number 42 Whatman™ filter paper in the bottom of each pot to prevent the loss of soil. Each blend was then added separately to each prepared 10-cm pot, to approximately 1.27 cm (0.5 in.) from the rim. Twenty ryegrass seeds were added separately to each blend. All pots were randomly placed on tables in the greenhouse under lights and allowed to grow. Ryegrass was selected as the model plant species and, therefore, was the only plant species tested in this screening test.

Ryegrass was chosen because it is less sensitive to high salt content and to nutrient deficiency. Information obtained about ryegrass can be used to evaluate other plant species with similar physiological responses to sediment salt and nutrient content.

The greenhouse setup, procedures, and preparation of blends were similar to those of the previous screening tests. The experimental design of screening tests for both non-cement and cement-amended treated/decontaminated dredged material are shown in Tables 3 and 4, respectively.

Table 3
Experimental Design for Non-Cement Decontaminated NY/NJ Harbor Dredged Material Manufactured Topsoil Screening Test 3

Treatments	
Blend 1	ORG-X NY/NJ Harbor dredged material
Blend 2	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 3	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 4	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 5	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 6	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 7	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 8	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 9	ORG-X NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 10	Fertile reference control
Plant Species	
Lolium multiflorum Lam (Ryegrass - Gulf Annual)	
Experimental Design	
Growth Test 10 treatments x 1 species x 4 replicates completely randomized block design 10 x 1 x 4 = 40 experimental units (4-in. planting pots).	

Table 4
Experimental Design for Cement-Amended Decontaminated NY/NJ Harbor Dredged Material Manufactured Topsoil Screening Test 3

Treatments	
Blend 1	Cement NY/NJ Harbor dredged material
Blend 2	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 3	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 4	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 5	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 6	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 7	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 8	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 9	Cement NY/NJ Harbor dredged material + cellulose + BIONSOIL™ biosolids
Blend 10	Fertile reference control
Plant Species	
Lolium multiflorum Lam (Ryegrass - Gulf Annual)	
Experimental Design	
Growth Test 10 treatments x 1 species x 4 replicates completely randomized block design 10 x 1 x 4 = 40 experimental units (4-in. planting pots).	

3 Statistical Analysis

Experimental data were analyzed using analysis of variance (ANOVA) procedures of the Statistical Analysis System (SAS Institute, Inc., 1989). Tests of normality were performed using the Shapiro-Wilk statistic; homogeneity of variance was evaluated using Levene's test; comparisons of means were performed using Duncan's Multiple Range Test. In this report, statements of statistical significance without specific indication of probability level refer to $P < 0.05$.

4 Results and Discussion

Dredged Material Characterization

The concentration of the various inorganic and organic chemicals in the original NY/NJ Harbor Newton Creek dredged material and Blend 5 from Screening Tests 1 and 2 are shown in Tables 5-12. Bulk metal concentrations in both Blend 5 screening tests were considerably below those specified in 40 CFR Part 503 guidelines (Table 5). The U.S. Environmental Protection Agency (USEPA) published 40 CFR Part 503 regulations to indicate the acceptable level of metals in agricultural soils from the application of biosolids derived from sewage sludge (USEPA 1990; 1993; 1995). These guidelines are based on the risk to animals exposed to grazing on these fields and give perspective as to the relative bulk chemical analyses in soils for certain metals (USEPA 1989).

Table 5
NY/NJ Harbor Dredged Material Metal Concentrations

Analytes	NY/NJ mg/kg	Blend 5 NY/NJ Screening Test 1 mg/kg	Blend 5 NY/NJ Screening Test 2 mg/kg	EPA 503 Regulation mg/kg
Zinc	1,725.0	514.0	598.0	2,800.0
Cadmium	37.1	7.87	11.32	39.0
Lead	617.0	231.0	207.0	300.0
Copper	1,172.0	393.0	394.0	1,500.0
Chromium	377.0	140.0	138.0	
Mercury	1.3			17.0
Silver	18.4	6.1	5.7	
Arsenic	33.5	12.5	14.4	41.0
Beryllium	<0.58	<0.33	<0.4	
Nickel	297.0	95.0	104.0	420.0
Antimony	10.3	2.1	5.14	
Selenium	3.24	3.32	3.06	
Thallium	<2.8	<1.64	<2.02	

Table 6
NY/NJ Harbor Dredged Material Pesticide Concentrations

Analytes	NY/NJ mg/kg	Blend 5 NY/NJ Screening Test 1 mg/kg	Blend 5 NY/NJ Screening Test 2 mg/kg
alpha-BHC	ND	<0.060	<0.076
a-Chlordaqne	ND	<0.060	0.026
Aldrin	0.075	<0.060	<0.076
beta-BHC	ND	<0.060	<0.076
delta-BHC	ND	<0.060	<0.076
4,4'-DDD	0.162	<0.121	<0.152
4,4'-DDE	0.152	<0.121	0.022
4,4-DDT	ND	0.143	0.064
Dieldrin	0.075	<0.121	0.020
Endrin	ND	<0.121	<0.152
Endrin Aldehyde	ND	<0.121	<0.152
Endrin Ketone	ND	<0.121	<0.152
Endosulfan sulfate	ND	<0.121	<0.152
gamma-BHC (Lindane)	ND	<0.060	<0.076
g-Chlordane	ND	<0 .060	0.022
Heptachlor	ND	<0.060	<0.076
Heptachlor epoxide	ND	<0.060	<0.076
Methoxychlor	ND	<0.605	<0.758
Toxaphene	ND	<0.047	<0.578
Ebdosulfan I	ND	<0.060	<0.076
Ebdosulfan II	ND	<0.121	<0.152

Notes: ND = Analyte was not detected in sample.
< = below detection limit.

Table 7
NY/NJ Harbor Dredged Material PAH Concentrations

Analytes	NY/NJ mg/kg	Blend 5 NY/NJ Screening Test 1 mg/kg	Blend 5 NY/NJ Screening Test 2 mg/kg
Phenol	0.585	<0.866	<1.126
3-4-Methylphenol	1.390	<1.035	<1.346
Naphthalene	2.729	0.659J	0.663J
Acenaphthylene	1.289	0.914J	0.774J
Acenaphthene	1.042	0.314J	<0.674
Dibenzofuran	1.172	0.312	0.191J
Fluorene	1.389	0.581J	0.236J
Phenanthrene	6.586	2.312J	1.378J
Anthracene	3.702	1.590J	0.821J
Di-n-butylphthalate	1.227	0.441BJ	0.671BJ
Fluoranthene	10.324	8.244	1.923J
Pyrene	7.101	3.604J	1.493J
Butylbenzylphthalate	1.473	0.600J	0.536J
Benzo(a)anthracene	4.484	3.128J	1.284J
Chrysene	4.564	3.717J	1.791J
Di-n-octylphthalate	3.523	0.379J	0.587J
Benzo(b)fluoranthene	2.922	2.375J	1.652J
Benzo(k)fluoranthene	1.107	1.043J	0.577J
Benzo(e)pyrene	2.125	1.639J	0.577J
Benzo(a)pyrene	2.551	1.966J	1.430J
Perylene	0.949	0.602J	0.699J
Indeno(1,2,3-cd)pyrene	1.076	1.073J	1.197J
Dibenz(a,h)anthracene	0.397	0.430J	0.511J
Benzo(g,h,i)perylene	1.254	1.215J	1.608J

Notes: J = Estimated below quantitation limit.
B = present in blank.

Table 8
NY/NJ Harbor Dredged Material PCB Concentrations

Analytes	NY/NJ µg/kg	Blend 5 NY/NJ Screening Test 1 µg/kg	Blend 5 NY/NJ Screening Test 2 µg/kg
2-Mono CB	57.0	25.9	3.7
4,4'-DiCB	65.0	39.7	14.6
2,4,4'-TriCB	168.0	80.4	27.2
2,2',5,5'-TetraCB	269.0	188.0	49.6
3,3',4,4"-TetraCB	14.0	8.0	4.3
2,3',4,4'-PentaCB	6.0	3.1[1]	2.3
2,3,3',4,4'PentaCB	67.0	38.9	14.6
3,3',4,4',5-PentaCB	0.4	0.25	0.13
2,3,3',4,4',5-HexaCB	17.0	6.8	4.8
2,3',4,4',5,5'-HexaCB	ND	<0.6	<0.3
2,2',3,4,4',5,5'-HeptaCB	74.0	43.5	44.0
2,2',3,3',4,4',5,5'-OctaCB	17.0	9.8	11.2
2,2',3,3',4,4',5,5',6-NonaCB	12.0	7.0	7.5
DecaCB	7.0	5.3	5.1
Total MonoCB	109.0	43.9	9.5
Total DiCB	379.0	291.0	42.4
Total TriCB	728.0	400.0	126.0
Total TetraCB	1,588.0	1,030.0	302.0
Total PentaCB	1,237.0	672.0	334.0
Total HexaCB	809.0	392.0	377.0
Total HeptaCB	295.0	179.0	172.0
Total OctaCB	96.0	45.6	53.8
Total NonaCB	20.0	10.4	13.6

Notes: ND = analyte not detected in sample.
[1] EMPC = Estimated maximum possible concentration.

Table 9
NY/NJ Harbor Dredged Material Bulk Dioxin Concentrations

Analytes	NY/NJ pptr	Blend 5 NY/NJ Screening Test 1 pptr	Blend 5 NY/NJ Screening Test 2 pptr
2,3,7,8-TCDD	40.0	15.2	14.2
1,2,3,7,8-PeCDD	57.0	19.8	17.4
1,2,3,4,7,8-HxCDD	56.0	24.1	24.1
1,2,3,6,7,8-HxCDD	142.0	49.9	51.3
1,2,3,7,8,9-HxCDD	139.0	60.6	62.1
1,2,3,4,6,7,8-HpCDD	2,022.0	682.0	702.0
1,2,3,4,6,7,8,9-OCDD	17,453.0	5,290.0	5,620.0
2,3,7,8-TCDF	340.0	123.0	109.0
1,2,3,7,8-PeCDF	311.0	101.0	94.7
2,3,4,7,8-PeCDF	152.0	49.1	49.5
1,2,3,4,7,8-HxCDF	1,303.0	484.0	472.0
1,2,3,6,7,8-HxCDF	454.0	171.0	166.0
2,3,4,6,7,8-HxCDF	184.0	80.4	80.3
1,2,3,7,8,9-HxCDF	25.0	3.7	2.8
1,2,3,4,6,7,8-HpCDF	4,958.0	1,430.0	1,470.0
1,2,3,4,7,8,9-HpCDF	110.0	37.2	40.0
1,2,3,4,6,7,8,9-OCDF	4,418.0	1,360.0	1,360.0
PeCDF		1,280.0	
Total TCDD	248.0		
Total PeCDD	378.0		
Total HxCDD	1,370.0	1,910.0	1,910.0
Total HpCDD	4,450.0	1,800.0	1,840.0
Total Furans, pptr			
Total TCDF	2,371.0		
Total PeCDF	2,853.0		
Total HxCDF	5,175.0		
Total HpCDF	6,068.0		

Note: pptr = parts per trillion.

Table 10
Bulk Dioxin TEQ Values for NY/NJ Harbor Dredged Material

Analytes	NY/NJ pptr	Blend 5 NY/NJ Screening Test 1 pptr	Blend 5 NY/NJ Screening Test 2 pptr
2,3,7,8-TCDD	40.0	15.2	14.2
1,2,3,7,8-PeCDD	28.5	9.90	8.7
1,2,3,4,7,8-HxCDD	5.6	2.41	2.41
1,2,3,6,7,8-HxCDD	14.2	4.99	5.13
1,2,3,7,8,9-HxCDD	13.9	6.06	6.21
1,2,3,4,6,7,8-HpCDD	20.22	6.82	7.02
1,2,3,4,6,7,8,9-OCDD	17.45	5.29	5.62
2,3,7,8-TCDF	34.0	12.30	10.90
1,2,3,7,8-PeCDF	15.55	5.05	4.74
2,3,4,7,8-PeCDF	76.0	24.55	24.75
1,2,3,4,7,8-HxCDF	130.0	48.40	47.20
1,2,3,6,7,8-HxCDF	45.4	17.10	16.6
2,3,4,6,7,8-HxCDF	18.4	8.04	8.03
1,2,3,7,8,9-HxCDF	2.5	0.37	0.28
1,2,3,4,6,7,8-HpCDF	49.58	14.302	14.7
1,2,3,4,7,8,9-HpCDF	1.10	0.372	0.4
1,2,3,4,6,7,8,9-OCDF	4.418	1.36	1.36
SUM TEQ	517.12	182.512	178.25

Note: pptr = parts per trillion.

Table 11
Bulk and Leachate Dioxin TEQ Values for NY/NJ Harbor Dredged Material

Analytes	NY/NJ pptr	Blend 5 NY/NJ Screening Test 1 pptrt	Blend 5 NY/NJ Screening Test 2 Bulk Concentration pptr	Blend 5 NY/NJ Screening Test 2 TCLP Leachate pptr
2,3,7,8-TCDD	15.2	<8.9	14.2	<8.5
1,2,3,7,8-PeCDD	9.90	<7.0	8.7	<6.2
1,2,3,4,7,8-HxCDD	2.41	<0.96	2.41	<0.98
1,2,3,6,7,8-HxCDD	4.99	<0.68	5.13	<0.69
1,2,3,7,8,9-HxCDD	6.06	<0.86	6.21	<0.87
1,2,3,4,6,7,8-HpCDD	6.82	<0.097	7.02	<0.096
1,2,3,4,6,7,8,9-OCDD	5.29	<0.016	5.62	0.063
2,3,7,8-TCDF	12.3	<0.65	10.9	<0.6
1,2,3,7,8-PeCDF	5.05	<0.475	4.74	<0.38
2,3,4,7,8-PeCDF	24.55	<3.65	24.75	<2.9
1,2,3,4,7,8-HxCDF	48.4	<0.75	47.2	<0.75
2,3,4,6,7,8-HxCDF	8.04	<0.66	8.03	**0.48**
1,2,3,7,8,9-HxCDF	0.37	<0.78	0.28	<0.78
1,2,3,4,6,7,8-HpCDF	14.3	**0.049**	14.7	**0.086**
1,2,3,4,7,8,9-HpCDF	0.372	<0.069	0.4	<0.066
1,2,3,4,6,7,8,9-OCDF	1.36	<0.011	1.36	<0.011
Total TEQ[1]	182.512	<26.09	178.25	<23.92
Total TEQ[2]		**0.049**		**0.629**

Note: pptr = parts per trillion; bold type indicates numbers above detection limits.
[1] Used all numbers (above and below detection limits).
[2] Used only numbers above detection limits.

Table 12
NY/NJ Harbor Dredged Material Bulk PCB and TCLP Leachate Concentrations

Analytes	NY/NJ µg/kg	Blend 5 NY/NJ Screening Test 1 pptr	Blend 5 NY/NJ Screening Test 2 Bulk Concentration µg/kg	Blend 5 NY/NJ Screening Test 2 TCLP Leachate pptr
2-Mono CB	25.9	12.1	3.7	0.08
4,4'-DiCB	39.7	1.8	14.6	0.27
2,4,4'-TriCB	80.4	2.3	27.2	0.41
2,2',5,5'-TetraCB	188.0	2.4	49.6	0.49[1]
3,3',4,4'-TetraCB	8.0	0.12	4.3	0.04
2,3',4,4'-PentaCB	3.1	0.08[1]	2.3	<0.09
2,3,3',4,4'-PentaCB	38.9	0.44	14.6	0.09
3,3',4,4',5-PentaCB	0.25	<0.04	0.13	<0.08
2,3,3',4,4',5-HexaCB	6.8	<0 .14	4.8	<0.10
3,3',4,4',5,5'-HexaCB	<0.6	<0.06	<0.30	<0.10
2,2',3,4,4',5,5'-HeptaCB	43.5	0.65	44.0	0.54
2,2',3,3',4,4',5,5'-OctaCB	9.8	0.12	11.2	0.11[1]
2,2',3,3',4,4',5,5',6-NonaCB	7.0	<0.10	7.5	<0.20
DecaCB (#209)	5.3	<0.20	5.1	<0.30
Total MonoCB	43.9	15.4	9.5	0.08
Total DiCB	291.0	14.2	42.4	0.85
Total TriCB	400.0	18.6	126.0	1.9
Total TetraCB	1,030.0	14.1	302.0	1.7
Total PentaCB	672.0	4.7	334.0	2.1
Total HexaCB	392.0	5.4	377.0	2.7
Total HeptaCB	179.0	2.2	172.0	0.98
Total OctaCB	45.6	0.31	53.8	0.11[1]
Total NonaCB	10.4	<0.10	13.6	<0.20

[1] EMPC (estimated maximum possible concentration).

An evaluation of pesticide and PAH analyses of Blend 5 revealed extremely low concentrations or values below detection limits (Tables 6 and 7). PCB levels in Blend 5 in Screeing Tests 1 and 2 were significantly lower that PCB levels in the original non-amended NY/NJ dredged material (Table 8). Bulk dioxin analysis of the original NY/NJ Harbor dredged material showed significantly higher concentrations of dioxin than those detected in Blend 5 (Table 9). Calculated total dioxin equivalent (TEQ) values for NY/NJ Harbor dredged material and Blend 5 from Screening Tests 1 and 2 showed TEQ values higher than the average concentration of 7.5 pptr typically found in soils (Table 10) (USEPA 1990, 1995). Furthermore, the dioxin toxicity characteristic leaching procedure (TCLP) revealed very low concentrations or concentrations below detection limits (Table 11). TEQ values (using only numbers above detection limits to calculate TEQ values) of the TCLP leachate showed values below levels typically found in soils (Tables 11). Bulk PCB and TCLP leachate analyses for Blend 5 (collected at time of blending) are shown in Table 12. PCB TCLP leachate levels for Blend 5 were below detection limits or at levels considerably lower than the PCB bulk levels (Table 12).

The USEPA is promoting the reuse of biosolids by promulgating 40 CFR Part 503 regulations. The intent of the 503 regulations is to establish regulatory levels that prevent adverse effects on human health and the environment. Since the metal levels detected in Blend 5 were below USEPA acceptable levels for metals, Blend 5 would be considered acceptable materials on this basis. Therefore, metal content in Blend 5 from Screening Tests 1 and 2 should not be of public concern.

TCLP was developed to assess the solubilization and mobilization/immobilization of inorganic and organic chemicals in an acid landfill environment (USEPA 1988, 1989). The TCLP was developed to identify a characteristic RCRA hazardous waste and its potential impacts on human health and the environment if the waste was placed in an acid landfill environment (40 CFR Part 261). Organic leachate levels were considerably lower than bulk organic levels in Blend 5. In addition, calculated TEQ values for dioxin (using only numbers above detection limits) for the leachate showed values lower than those typically found in soils. This appears to indicate that organic chemicals are not being solubilized and leached from the blends.

Blending dredged material with organic matter will reduce the levels of organic contaminants in the blends. The addition of organic matter to the proprietary blends will result in adsorption and immobilization of most organic contaminants (Hamaker and Thompson 1972; Karickhoff, Brown, and Scott 1979). Organic contaminants, specifically dioxin, in soils may be a cause for concern to human exposure. The concentration of dioxin TEQs in the manufactured soil is ~25 times more than that observed in average North American soil (USEPA 1995). It should be pointed out that numerous studies have shown that dioxins are commonly found in soils throughout the world and that relatively little adverse impact to the general food supply is from soil residues that originate from site-specific sources such

as sewage sludge and other waste disposal operations (USEPA 1987). However, manufactured topsoil that has contaminants present of sufficient magnitude should have restricted use to sites that are limited to human exposure. Superfund sites, landfills, and abandoned mine sites are more appropriate sites for use of this material than sites that have more human exposure. The ultimate decision on the use of manufactured topsoil from NY/NJ Harbor Newton Creek dredged material will be made by the appropriate regulatory agencies involved.

TCLP data cannot be interpreted to plant uptake, it was developed to predict leachability of contaminants in an acid landfill environment. The soil mixture with cellulose and biosolids does have a binding and immobilizing effect on contaminants. The issue of bioavailability of contaminants in the manufactured soil requires additional evaluation. The Phase 2 demonstration should determine bioavailability to a greater extent using earthworm bioaccumulation tests. Table 9 compares the bulk analysis of the dredged material and the blends of manufactured topsoils. An apparent dilution can be observed. Limited TCLP data are available from the greenhouse test. More TCLP data will be collected in the Phase 2 NY/NJ field demonstration project.

TEQs are used to express toxicity and regulate open-water disposal. The TEQ values of the original NY/NJ Harbor Newton Creek dredged material and the blends (using numbers above and below detection) exceeded the 7.5 pptr normally found in native soils across North America. Therefore, because of concern about adverse impacts the elevated levels of organic chemicals (e.g., dioxin) may have on human health and the environment, use of Blend 5 should be limited to covers for superfund sites, mining sites, landfills, and similar degraded lands that normally have restricted human exposure. Table 13 shows soil fertility analysis and physical characterization of Blend 5.

Seed Germination Screening Test

New York/New Jersey Test 1

Figure 1 shows an overall view of the seed germination study after 14 days and results of the first test are shown in Table 14. An evaluation of the ANOVA indicated that seed germination was influenced by treatment ($P = 0.0001$), time ($P = 0.0001$), and species ($P = 0.0001$). Germination of all plant seeds in Blend 5 was significantly better than in Blends 4, 3, and 2, or in Blend 1 ($P < 0.05$) (Table 14). There was no significant difference in percent seed germination between Blends 5 and 6 (the fertile reference soil) for all species except vinca.

Table 13
Soil Fertility Analysis and Physical Characterization of Blend 5 Consisting of NY/NJ Harbor Dredged Material

Analytes	Blend 5 Screening Test 1	NY/NJ Dredged Material
Total Kjeldahl nitrogen, mg/kg	212.0	
Orthophosphate, mg/kg	10.0	
Magnesium, mg/kg	6,830.0	
Sodium, mg/kg	7,740.0	
Calcium, mg/kg	13,700.0	
Zinc, mg/kg	514.0	
Potassium, mg/kg	4,220.0	
Organic matter, percent	67.5	
CEC, meq/100 g	64.0	
pH	5.6	
Moisture, percent	68.6	
Specific gravity		2.44
Bulk density, lb/ft^3		
68.6 percent moisture		79.7
60.0 percent moisture		77.0
Proctor denisty, lb/ft^3		93.0
CI, $lb/in.^2$		145.0
Particle size		
Sand, percent		58.2
Silt, percent		23.2
Clay, percent		18.6

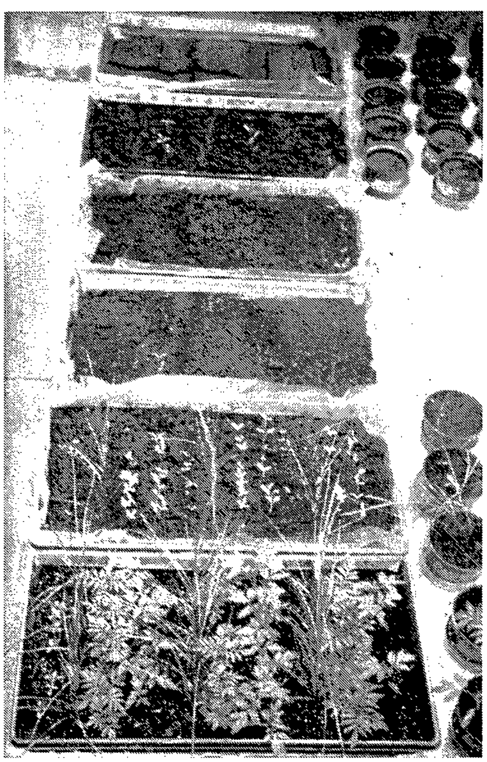

Figure 1. Overall view of the seed germination study after 14 days

The percentage germination of ryegrass was significantly higher (P < 0.05) in all blends than that of other plant species (P < 0.05). For example, the value for ryegrass was 97 percent, while values for tomato, marigold, and vinca were 70, 80, and 53 percent, respectively. Seed germination was in the order of ryegrass > marigold > tomato > vinca. Generally, germination percentages in Blends 4, 3, 2, and 1 did not differ significantly.

Table 14
Seed Germination Test 1 for NY/NJ Harbor Dredged Material

	Tomato, percent ± standard error		Marigold, percent ± standard error	
Blends	**14 Days**	**21 Days**	**14 Days**	**21 Days**
6 (control)	73.3 ± 15.6a	93.3 ± 2.4a	80.0 ± 8.1a	80.0 ± 8.1a
5	70.0 ± 14.7a	93.3 ± 2.4a	80.0 ± 10.8a	80.0 ± 10.8a
4	0.0 ± 0.0b	16.7 ± 8.5e	20.0 ± 4.1b	43.3 ± 4.7c
3	0.0 ± 0.0b	30.0 ± 17.8d	16.7 ± 6.2b	33.3 ±12.5d
2	0.0 ± 0.0b	40.0 ± 4.1c	0.0 ± 0.0c	53.3 ± 2.4b
1	0.0 ± 0.0b	0.0 ± 0.0f	0.0 ± 0.0c	0.0 ± 0.0e
	Ryegrass, percent ± standard error		**Vinca, percent ± standard error**	
Blends	**14 Days**	**21 Days**	**14 Days**	**21 Days**
6 (control)	95.0 ± 3.5a	95.0 ± 3.5a	63.3 ± 6.2a	66.7 ± 6.2a
5	96.7 ± 1.2a	96.7 ± 1.2a	53.3 ± 6.2b	60.0 ± 4.1a
4	15.0 ± 5.4b	68.3 ± 4.2b	0.0 ± 0.0c	0.0 ± 0.0b
3	11.7 ± 1.2b	60.0 ± 8.9b	0.0 ± 0.0c	3.3 ± 2.4b
2	10.0 ± 4.1b	51.7 ± 4.2b	0.0 ± 0.0c	3.3 ± 2.4b
1	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b

Note: Different letters indicate that values among blends and within species are significantly different at P < 0.05 (Duncan's multiple range test).

The movement of water from dredged material to seeds followed by uptake is essential for seed germination. Therefore, differences observed in seed germination among the different blends could be due to factors affecting the rate and extent of water movement from the manufactured soil blend to the seeds. For example, blends containing higher amounts of dredged material showed significantly lower seed germination (Table 14). This may be ascribed to the high degree of soil compaction or bulk density of the dredged material rather than to dredged material contamination. Generally, the presence of contaminants does not adversely impact seed germination, but has the greatest effect on the seedlings after germination.

Dredged material, with its high bulk density, decreases capillary water and vapor movement of water toward the seed, which may result in decreased imbibition or may physically restrict the swelling of the seed, thus impeding seed germination (Hagon and Chan 1977). High bulk density decreases soil aeration, which may also impede seed germination.

Tomato, vinca, and marigold are sensitive to salinity, while ryegrass is more salt tolerant. However, elevated salinity levels (15 to 55 ppt) may

have adversely affected overall seed germination by reducing the availability of water to the seed, reducing seed imbibition, and later reducing the percent seed germination. Ryegrass seed germination was significantly higher than germination of other plant species. This suggests that ryegrass seed may be more efficient in taking up water. In addition, it indicates that ryegrass seed may be able to complete germination at lower water contents than tomato, marigold, and vinca seeds.

The percentage of seed germination ANOVA showed some time-species and time-treatment interaction effect ($P = 0.009$). Germination of tomato seed in Blend 5 showed a significant increase after 21 days ($P < 0.05$); however, seed germination of marigold, ryegrass, and vinca did not change significantly after 21 days ($P > 0.05$). Further evaluation of the seed germination data reveals that germination was enhanced for all species after 21 days in Blends 4, 3, and 2 (Table 14). Even so, seed germination in these blends remained significantly lower than in Blends 5 and 6.

New York/New Jersey Test 2

Results from the second germination test paralleled results obtained from the first test. The ANOVA revealed a time ($P = 0.03$), treatment ($P = 0.0001$), and species ($P = 0.0001$) effect on seed germination. There was no significant difference between seed germination in Blend 5 and that in Blend 7 (fertile reference control), but both were significantly higher than values for Blends 6 (**new**), 4, 3, and 2, as well as Blend 1 (Table 15).

Table 15
Seed Germination Test 2 for NY/NJ Harbor Dredged Material

	Tomato, percent ± standard error		Marigold, percent ± standard error	
Blends	**14 Days**	**21 Days**	**14 Days**	**21 Days**
7 (control)	90.0 ± 4.1a	90.0 ± 4.1a	100.0 ± 0.0a	100.0 ± 0.0a
6[1]	0.0 ± 0.0c	13.3 ± 2.4d	0.0 ± 0.0d	0.0 ± 0.0
5	93.3 ± 4.7a	93.3 ± 4.7a	90.0 ± 5.0a	90.0 ± 5.0a
4	30.0 ± 14.7b	46.7 ± 17.8b	43.3 ± 8.5b	43.3 ± 8.5c
3	10.0 ± 4.1c	30.0 ± 4.1c	16.7 ± 2.4c	16.7 ± 2.4d
2	93.3 ± 4.7a	100.0 ± 0.0a	50.0 ± 4.1b	50.0 ± 4.1c
1	0.0 ± 0.0c	30.0 ± 17.8c	13.3 ± 9.4c	26.7 ± 12.5d
	Ryegrass, percent ± standard error		**Vinca, percent ± standard error**	
Blends	**14 Days**	**21 Days**	**14 Days**	**21 Days**
7 (control)	98.3 ± 1.2a	98.3 ± 1.2a	50.0 ± 8.2b	53.3 ± 6.2b
6[1]	23.3 ± 3.1c	33.3 ± 1.2d	0.0 ± 0.0d	0.0 ± 0.0d
5	98.3 ± 1.2a	100.0 ± 0.0a	86.7 ± 9.4a	90.0 ± 7.1a
4	50.0 ± 4.1b	60.0 ± 3.5b	0.0 ± 0.0d	0.0 ± 0.0d
3	45.0 ± 13.4b	48.3 ± 8.9b	0.0 ± 0.0d	0.0 ± 0.0d
2	100.0 ± 0.0a	100.0 ± 0.0a	16.7 ± 2.4c	26.7 ± 4.7c
1	1.7 ± 1.3d	8.3 ± 5.9e	0.0 ± 0.0d	0.0 ± 0.0d

Note: Different letters indicate that values among blends and within species are significantly different at $P < 0.05$ (Duncan's multiple range test).
[1] New NY/NJ Harbor dredged material blend.

Comparison of data obtained from Tests 1 and 2 revealed that the addition of BIONSOIL^{TM} biosolids positively affected seed germination ($P = 0.0001$). Generally, all plant species showed enhanced seed germination ($P < 0.05$) in Blends 5, 4, 3, and 2 as compared with somewhat similar blends in the first study. Time showed no significant effect on seed germination ($P < 0.05$). BIONSOIL^{TM} biosolids was added to the various blends as a source of nutrients and organic matter. The nutrient content of the blends probably affected plant growth but had very little direct impact on seed germination. The increase in seed germination more likely should be attributed to the decrease in bulk density brought about by the BIONSOIL^{TM} biosolids amendment. Oxygen availability, rate of water movement, and availability of water to the seeds all could have affected seed germination.

New York/New Jersey Test 3

Ryegrass seed did not germinate on day 14 in any of the blends with non-cement or cement-amended decontaminated dredged material (Table 16). However, seed germination was observed in Blends 9, 8, and 7 with non-cement decontaminated dredged material on day 21, while no seed germination was observed in any of the cement-amended decontaminated NY/NJ Harbor dredged material blends. Germination of ryegrass in Blend 9 was 22 percent, while values in Blends 7 and 8 were 58 percent (Table 16). Percent seed germination in all blends was significantly lower than in

Table 16
Seed Germination Test 3 Decontaminated NY/NJ Harbor Dredged Material

	Ryegrass Unwashed (cement-amended)		Ryegrass Unwashed (non-cement)	
Blends	14 Days, percent	21 Days, percent	14 Days, percent	21 Days, percent
10 (control)	95.0a	95.0a	95.0a	95.0a
9	0.0b	0.0b	0.0b	22.0c
8	0.0b	0.0b	0.0b	58.0b
7	0.0b	0.0b	0.0b	58.0b
6	0.0b	0.0b	0.0b	0.0d
5	0.0b	0.0b	0.0b	0.0d
4	0.0b	0.0b	0.0b	0.0d
3	0.0b	0.0b	0.0b	0.0d
2	0.0b	0.0b	0.0b	0.0d
1	0.0b	0.0b	0.0b	0.0d

	Ryegrass Washed (cement-amended)		Ryegrass Washed (non-cement)	
Blends	14 Days, percent	21 Days, percent	14 Days, percent	21 Days, percent
10 (control)	98.0a	98.0a	98.0a	98.0a
9	28.0d	30.0d	25.0d	22.0e
8	51.0c	54.0c	22.0d	22.0e
7	64.0b	51.0c	52.0b	77.0b
6	45.0c	49.0c	63.0b	68.0b
5	73.0b	76.0b	61.0b	75.0b
4	71.0b	77.0b	46.0c	55.0c
3	75.0b	91.0a	42.0c	53.0c
2	68.0b	91.0a	49.0c	60.0c
1	28.0d	33.0d	48.0c	46.0d

Note: Different letters indicate that values among blends and within species are significantly different at $P < 0.05$ (Duncan's multiple range test).

Blend 10 (fertile reference control) where a value of 95 percent was observed (Table 16).

The salinity levels in the various non-cement decontaminated blends ranged from 15 to 55 parts per thousand (ppt), while salinity levels in the cement-amended decontaminated blends ranged from 18 to 60 ppt. Generally, highest salinity levels and lowest seed germination percentages were observed in blends (both non-cement and cement-amended)containing the highest amounts of decontaminated dredged material.

Washing the treated/decontaminated NY/NJ Harbor dredged material decreased salinity levels to 4 ppt and improved seed germination in the various treated NY/NJ Harbor dredged material blends (Table 16). Even though seed germination was low (<90 percent), washing improved the productivity of the treated/decontaminated NY/NJ Harbor dredged material blends. Poor seed germination may be ascribed in part to elevated levels of salinity.

Cyperus esculentus, an emergent wetland plant, did not germinate or grow in the tests. The tubers used were not as viable as desired. New tubers were obtained for future tests.

Plant Growth Screening Test

New York/New Jersey Test 1

An overall view of the greenhouse screening tests is shown in Figure 2. Visual observations of leaf color, size, and shape as well as total aboveground biomass were used to evaluate the effects of the different NY/NJ Harbor manufactured soil blends on plant growth. An evaluation of the total aboveground biomass revealed that the best plant growth overall was in Blend 5 (Figures 3 and 4; Table 17).

An evaluation of the ANOVA showed that treatment ($P = 0.0001$) and species ($P = 0.0001$) influenced total aboveground biomass. There was also a treatment-species interaction effect on biomass ($P = 0.0001$). No plant growth occurred in Blends 4, 3, and 2 or Blend 1 (Figures 3 and 4, Table 17). Ryegrass biomass yield was significantly higher in Blend 6 (fertile reference control) when compared with Blend 5 containing dredged material from the NY/NJ Harbor. For example, ryegrass biomass yield from Blends 6 (fertile reference control) and 5 was 3.18 g and 0.30 g dry weights, respectively (Table 17).

Visual observations during the first 2 weeks on leaf color, size, and shape revealed similarities between plants growing in Blend 5 and those growing in Blend 6 (fertile reference control). However, at day 21, plant growth in Blend 5 appeared to be slower than in Blend 6 (fertile reference

Figure 2. Overall view of the greenhouse screening tests

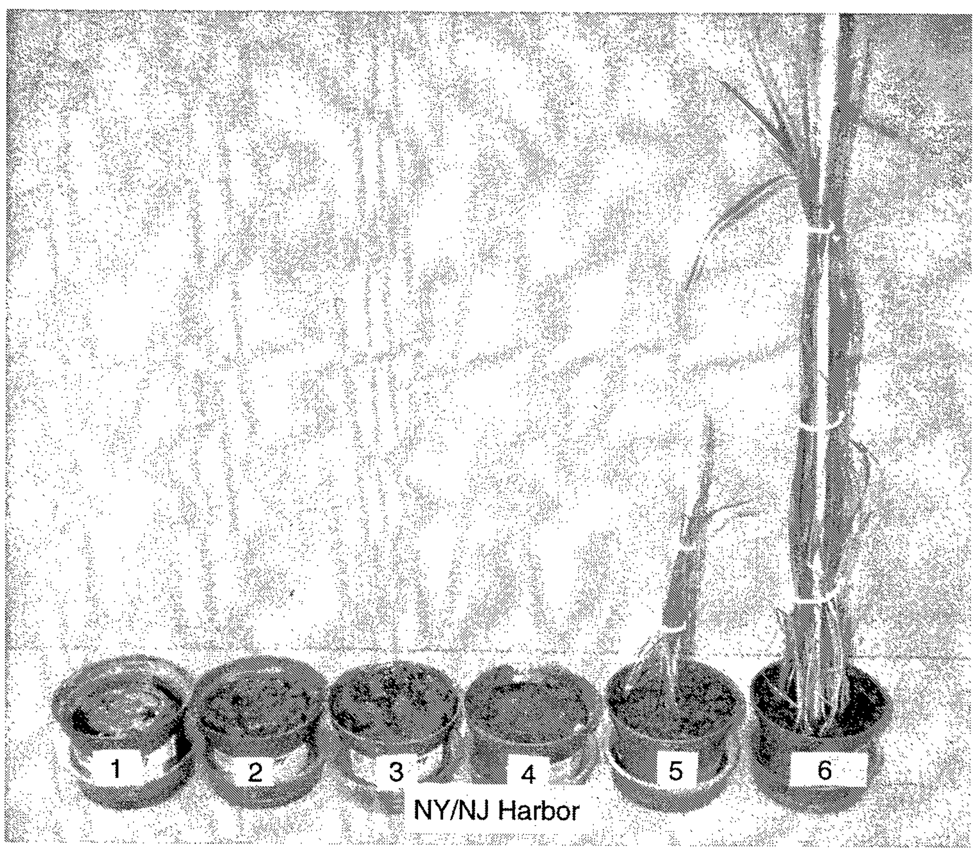

Figure 3. Ryegrass plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 1 (l to r, Blends 1, 2, 3, 4, 5, and 6)

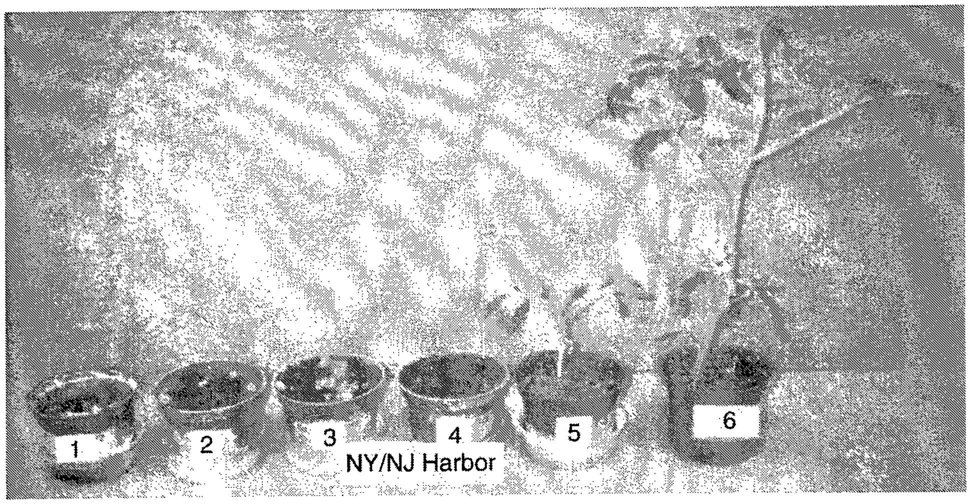

Figure 4. Tomato plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 1 (l to r, Blends 1, 2, 3, 4, 5, and 6)

Table 17
Aboveground Biomass from the NY/NJ Harbor Dredged Material Plant Growth Test 1

Blends	Tomato		Marigold	
	Fresh Weight, g	Dry Weight, g	Fresh Weight, g	Dry Weight, g
6 (control)	17.7	1.61a	14.7	1.76a
5	1.2	0.07b	0.5	0.03b
4	0.0	0.0b	0.0	0.0b
3	0.0	0.0b	0.0	0.0b
2	0.0	0.0b	0.0	0.0b
1	0.0	0.0b	0.0	0.0b

Blends	Ryegrass		Vinca	
	Fresh Weight, g	Dry Weight, g	Fresh Weight, g	Dry Weight, g
6 (control)	29.33	3.18a	1.11	0.170a
5	2.9	0.30b	0.2	0.001b
4	0.0	0.0c	0.0	0.0b
3	0.0	0.0c	0.0	0.0b
2	0.0	0.0c	0.0	0.0b
1	0.0	0.0c	0.0	0.0b

Note: Different letters indicate that values among blends and within species are significantly different at $P < 0.05$ (Duncan's multiple range test).

control). Leaf color gradually changed from green to yellow and leaves were not as broad as on those plants growing in the fertile reference soil. Tomato plants developed a purple color on the leaf petioles and veins caused by anthocyanin formation. This phosphorus deficiency response was also observed on the stems. There were also dead necrotic areas on the leaves and petioles, which suggests phosphorus deficiency. Yellow color and narrow leaves were ascribed to nitrogen (nutrient) deficiency in the manufactured topsoil blend as a result of plants depleting nitrogen and other nutrients in the blend.

On day 22, soluble ammonium-nitrate and Miracle Gro^{TM} (13N-13P-13K) were added to all of the NY/NJ Harbor dredged material blends to increase the manufactured topsoil fertility. The addition of nutrients appeared to enhance plant growth. At the end of 7 weeks, visual observations of leaf color and shape revealed similarities between ryegrass and tomato growth in Blend 5 and in Blend 6 (fertile reference control), with regard to leaf color and shape. However, plants growing in Blend 6 (fertile reference control) were significantly larger than those growing in Blend 5 (Figures 3 and 4). If soluble ammonium-nitrate and Miracle Gro^{TM} (13N-13P-13K) had been added, these differences in growth probably would have been negligible.

Concentrations of PCBs, dioxin, pesticides, metals, and PAHs in ryegrass leaves are shown in Tables 18-22, respectively. These data revealed extremely low concentrations or values well below detection limits (Tables 18-22). These results indicate that the organic and inorganic chemicals present in Blend 5 were not readily available for uptake by ryegrass. This suggests that the physical and chemical composition of Blend 5 probably immobilized and lowered the bioavailable fraction of the chemical constituents. Since dioxins are not readily taken up by plants from the soil, the major concern for plant dioxin contamination is more likely from atmospheric deposition than from plant uptake (Bacci et al. 1992).

Table 18
PCB Concentrations in Ryegrass Leaves Harvested from Blend 5

Analytes	Ryegrass Content ppb	Analytes	Ryegrass Content ppb
2-Mono CB	0.22	2,2',3,3',4,4',5,5',6-NonaCB	<0.03
4,4'-DiCB	0.32	DecaCB (#209)	<0.03
2,4,4'-TriCB	0.90	Total MonoCB	0.52
2,2',5,5'-TetraCB	0.48	Total DiCB	3.6
3,3',4,4'-TetraCB	0.05	Total TriCB	3.8
2,3',4,4'-PentaCB	<0.007	Total TetraCB	3.0
2,3,3',4,4'-PentaCB	0.25	Total PentaCB	2.3
3,3',4,4',5-PentaCB	<0.008	Total HexaCB	2.2
2,3,3',4,4',5-HexaCB	0.05	Total HeptaCB	0.95
3,3',4,4',5,5'-HexaCB	<0.01	Total OctaCB	0.11[1]
2,2',3,4,4',5,5'-HeptaCB	0.24	Total NonaCB	<0.03
2,2',3,3',4,4',5,5'-OctaCB	0.03[1]		

Note: ppb = parts per billion.
[1] EMPC (estimated maximum possible concentration).

Table 19
Dioxin Concentrations in Ryegrass Leaves Harvested from Blend 5

Analytes	Rygrass Content, pptr	TEQ Values, pptr
2,3,7,8-TCDD	1.8	1.80
1,2,3,7,8-PeCDD	1.7[1]	0.85
1,2,3,4,7,8-HxCDD	1.1	0.11
1,2,3,6,7,8-HxCDD	1.8[1]	0.18
1,2,3,7,8,9-HxCDD	2.2[1]	0.22
1,2,3,4,6,7,8-HpCDD	10.7[1]	0.11
1,2,3,4,6,7,8,9-OCDD	91.2	0.09
2,3,7,8-TCDF	3.6	0.36
1,2,3,7,8-PeCDF	2.3	0.12
2,3,4,7,8-PeCDF	2.1	1.05
1,2,3,4,7,8-HxCDF	6.5	0.65
1,2,3,6,7,8-HxCDF	3.2	0.32
2,3,4,6,7,8-HxCDF	3.0[1]	0.30
1,2,3,7,8,9-HxCDF	1.2	0.12
1,2,3,4,6,7,8-HpCDF	14.2	0.14
1,2,3,4,7,8,9-HpCDF	1.8	0.02
1,2,3,4,6,7,8,9-OCDF	15.9	0.02
Total TCDD	4.9	
Total PeCDD	1.1	
Total HxCDD	5.6	1,910.0
Total HpCDD	12.3	1,800.0
Total TCDF	29.4	
Total PeCDF	19.8	
Total HxCDF	22.6	
Total HpCDF	24.7	
Total TEQ		**6.45**

Note: pptr = parts per trillion.
[1] EMPC (estimated maximum possible concentration).

Table 20
Pesticide Concentrations in Ryegrass Leaves Harvested from Blend 5

Analytes	Ryegrass Content, mg/kg	Analytes	Ryegrass Content, mg/kg
alpha-BHC	ND	Endrin Aldehyde	ND
a-Chlordaqne	ND	Endosulfan I	ND
Aldrin	0.075	Endosulfan II	ND
beta-BHC	ND	Endosulfan sulfate	ND
delta-BHC	ND	gamma-BHC (Lindane)	ND
4,4'-DDD	0.162	g-Chlordane	ND
4,4'-DDE	0.152	Heptachlor	ND
4,4-DDT	ND	Heptachlor epoxide	ND
Dieldrin	0.075	Methoxychlor	ND
Endrin	ND	Toxaphene	ND

Note: ND = analyte not detected in sample.

Table 21
Metal Concentrations in Ryegrass Leaves Harvested from Blend 5

Analytes	Ryegrass Content, mg/kg	Analytes	Ryegrass Content, mg/kg
Silver	<0.382	Nickel	24.60
Arsenic	<0.763	Lead	1.59
Beryllium	<0.191	Antimony	<0.763
Cadmium	2.63	Selenium	3.17
Chromium	0.577	Thallium	<0.954
Copper	41.90	Zinc	159.0

Table 22
PAH Concentrations in Ryegrass Leaves Harvested from Blend 5

Analytes	Ryegrass Content, mg/kg	Analytes	Ryegrass Content, mg/kg
Phenol	<11.363	3-Nitroaniline	<14.081
bis(2-Chloroethyl)ether	<14.946	Acenaphthene	<4.999
2-Chlorophenol	<8.490	2,4-Dinitrophenol	<26.008
1,3-Dichlorobenzene	<7.240	4-Nitrophenol	<14.466
1,4-Dichlorobenzene	<6.888	Dibenzofuran	<2.759
1,2-Dichlorobenzene	<7.462	Diethylphthalate	3.386BJ
2,2'-oxybis(1-Chloropropane)	<15.097	4-Chlorophenyl-phenylether	<6.329
Benzyl alcohol	<34.578	Fluorene	<3.438
2-Methylphenol	<14.274	4-Nitroaniline	<13.637
3/4-Methylphenol	<12.746	4,6-Dinitro-2-methylphenol	<20.817
N-Nitroso-di-n-propylamine	<17.433	N-Nitrosodiphenylamine	<6.371
Hexachloroethane	<14.235	4-Bromophenyl-phenylether	<10.213
Nitrobenzene	<8.669	Hexachlorobenzene	<7.565
Isophorone	<4.823	Pentachlorophenol	<11.309
2-Nitrophenol	<12.424	Phenanthrene	<2.963
2,4-Dimethylphenol	<9.875	Anthracene	<2.952
bis(2-Chloroethoxy)methane	<10.173	Di-n-butylphthalate	<1.686
Benzoic acid	14.749J	Fluoranthene	<2.196
2,4-Dichlorophenol	<8.868	Pyrene	<1.396
1,2,4-Trichlorobenzene	<7.247	Butylbenzylphthalate	<2.186
Naphthalene	<2.962	3,3'-Dichlorobenzidine	<5.180
4-Chloroaniline	<6.706	bis(2-Ethylhexyl)phthalate	1.813BJ
Hexachlorobutadiene	<9.016	Benzo(a)anthracene	<1.569
4-Chloro-3-methylphenol	<9.108	Chrysene	<1.801
2-Methylnaphthalene	<4.042	Di-n-octylphthalate	0.770
Hexachlorocyclopentadiene	<9.957	Benzo(b)fluoranthene	<1.067
2,4,6-Trichlorophenol	<10.647	Benzo(k)fluoranthene	<1.130
2,4,5-Trichlorophenol	<9.854	Benzo(e)pyrene	<1.268
2-Chloronaphthalene	<4.398	Benzo(a)pyrene	<1.205
2-Nitroaniline	<14.920	Perylene	<1.313
Dimethylphthalene	<3.448	Indeno(1,2,3-cd)pyrene	<1.402
2,6-Dinitrotoluene	<13.369	Dibenz(a,h)anthracene	<1.865
2,4-Dinitrotoluene	<9.895	Benzo(g,h,i)perylene	<1.593
Acenaphthylene	<2.809		

Note: J = estimated below quantitation limit.
B = present in blank.

New York/New Jersey Test 2

The results from the second growth test showed that the additional 10 percent BIONSOIL™ biosolids added to the various blends did enhance plant biomass (Table 23; Figures 5-8). An evaluation of the ANOVA revealed a significant treatment-species interaction effect on aboveground plant biomass ($P = 0.0001$). Tomato, marigold, ryegrass, and vinca did not grow in Blends 4, 3, and 2 in Screening Test 1 (Table 17). However, the increase of BIONSOIL™ biosolids in Screening Test 2 had a positive impact on ryegrass biomass (Table 23).

Table 23
Aboveground Biomass from the NY/NJ Harbor Dredged Material Plant Growth Test 2

Blends	Tomato		Marigold	
	Fresh Weight, g	Dry Weight, g	Fresh Weight, g	Dry Weight, g
7 (control)	20.12	2.45a	4.2	0.5a
6[1]	0.05	0.0003c	0.0	0.0b
5	1.02	0.13b	2.92	0.39a
4	1.10	0.01c	0.0	0.0b
3	0.0	0.0c	0.0	0.0b
2	0.0	0.0c	0.0	0.0b
1	0.0	0.0c	0.0	0.0b

Blends	Ryegrass		Vinca	
	Fresh Weight, g	Dry Weight, g	Fresh Weight, g	Dry Weight, g
7 (control)	16.2	2.25a	1.2	0.23a
6[1]	2.0	0.36c	0.0	0.0b
5	13.60	1.5a	0.033	0.004b
4	5.14	0.98b	0.0	0.0b
3	5.12	0.86b	0.0	0.0b
2	0.5	0.14c	0.0	0.0b
1	0.05	0.003d	0.0	0.0b

Note: Different letters indicate that values among blends and within species are significantly different at $P < 0.05$ (Duncan's multiple range test).
[1] New NY/NJ Harbor dredged material blend.

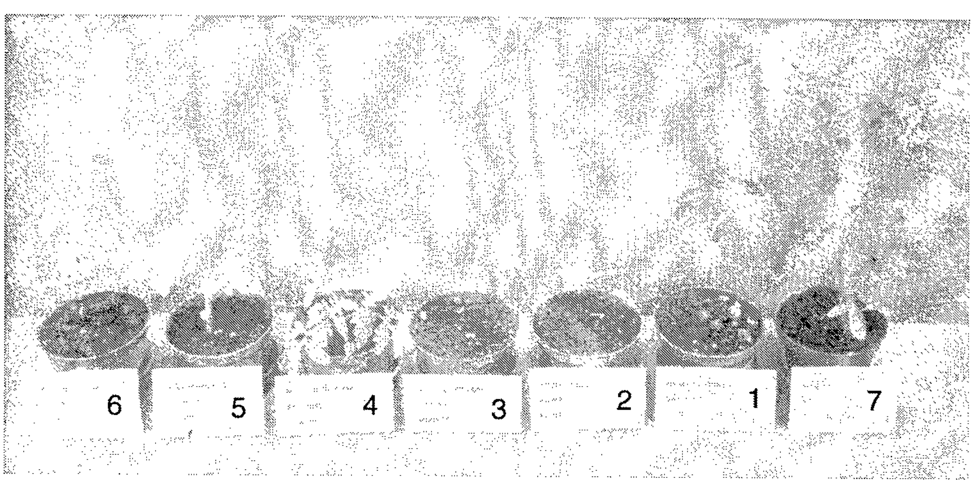

Figure 5. Tomato plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 2 (l to r, Blends 6, 5, 4, 3, 2, 1, and 7)

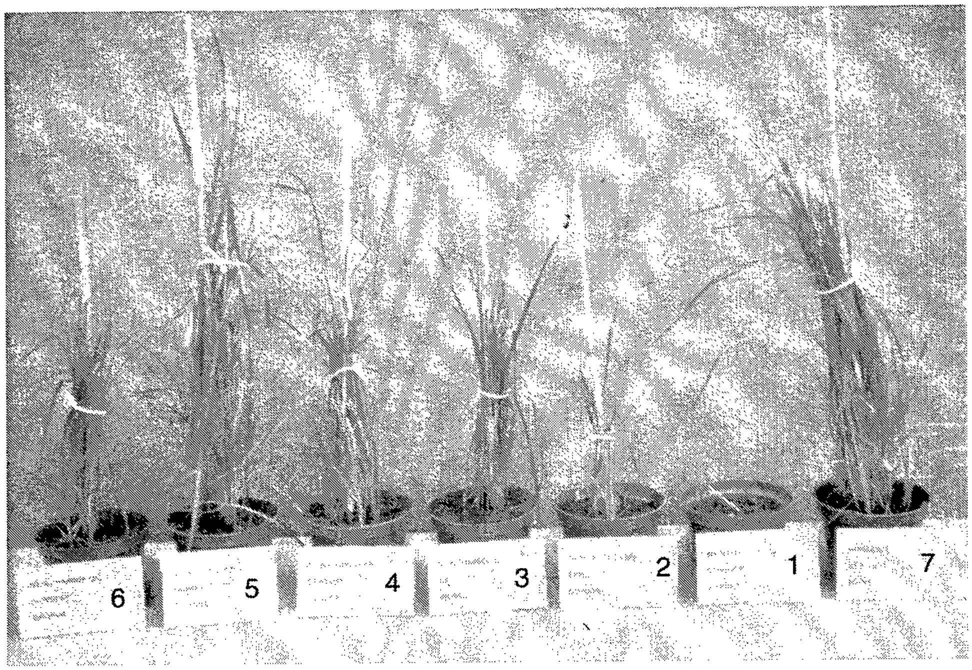

Figure 6. Ryegrass plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 2 (l to r, Blends 6, 5, 4, 3, 2, 1, and 7)

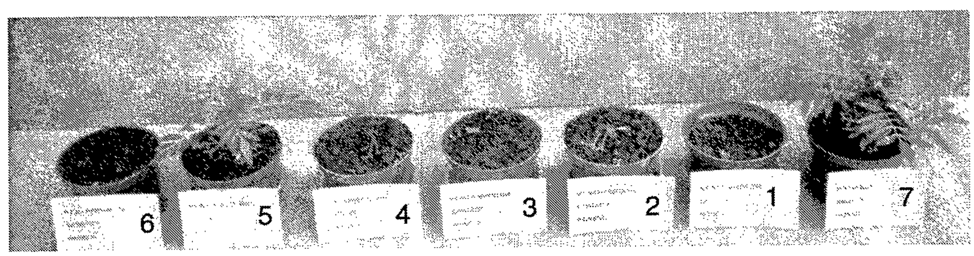

Figure 7. Marigold plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 2 (l to r, Blends 6, 5, 4, 3, 2, 1, and 7)

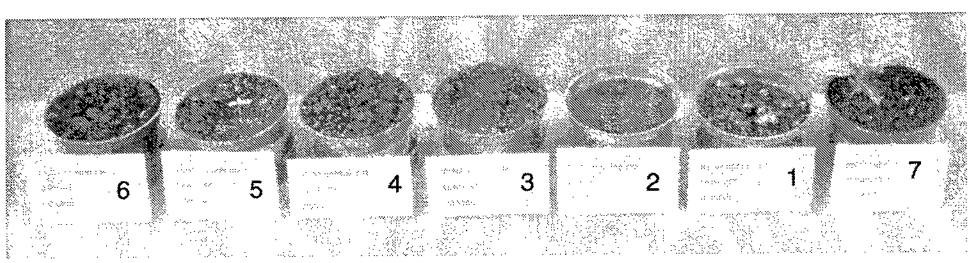

Figure 8. Vinca plants in the various NY/NJ Harbor dredged material blends at 7 weeks, Plant Growth Test 2 (l to r, Blends 6, 5, 4, 3, 2, 1, and 7)

New York/New Jersey Test 3

The manufactured soil blends using materials from Metcalf and Eddy, Inc., were not very productive. Ryegrass did not grow in any of the blends prepared with ORG-X + cement-amended decontaminated NY/NJ Harbor dredged material (Table 24). Some plant growth was observed in Blends 9, 8, and 7 prepared with non-cement decontaminated NY/NJ Harbor dredged

material, but plant biomass from these blends was significantly lower than that from Blend 10 (fertile reference control). For example, ryegrass biomass harvested from Blend 10 was 1.56 g dry weight, while plant biomass yields obtained from Blends 9, 8, and 7 were 0.16, 0.09, and 0.03 g dry weight, respectively.

There was also a direct relationship between salinity and the amount of decontaminated dredged material in the blends. As the amount of decontaminated dredged material increased in the blends, salinity also increased. Salinity levels ranged from 16 to 60 ppt, with the highest levels associated with higher amounts of ORG-X + cement-amended decontaminated NY/NJ Harbor dredged material.

After washing the decontaminated dredged material, salinity levels decreased and ranged from 2 to 4 ppt, and this improved plant growth to a level equal to or greater than that in the untreated Blend 5 (Table 24). Therefore, lack of plant growth in these blends may be ascribed to high salinity levels, pH, which was 8.3, or nutrient deficiency and not to contaminants, since the dredged material had been treated to remove or immobilize the inorganic and organic chemicals.

Table 24
Aboveground Biomass from the Untreated and Decontaminated NY/NJ Harbor Dredged Material

	Ryegrass Unwashed (cement-amended)		Ryegrass Unwashed (non-cement)	
Blends	**Wet Weight, g**	**Dry Weight, g**	**Wet Weight, g**	**Dry Weight, g**
10 (control)	9.89	1.56a	9.89	1.56a
9	0.0	0.0b	0.33	0.16b
8	0.0	0.0b	0.14	0.09c
7	0.0	0.0b	0.05	0.03c
6	0.0	0.0b	0.0	0.0c
5	0.0	0.0b	0.0	0.0c
4	0.0	0.0b	0.0	0.0c
3	0.0	0.0b	0.0	0.0c
2	0.0	0.0b	0.0	0.0c
1	0.0	0.0b	0.0	0.0c
	Ryegrass Unwashed (cement-amended)		**Ryegrass Unwashed (non-cement)**	
Blends	**Wet Weight, g**	**Dry Weight, g**	**Wet Weight, g**	**Dry Weight, g**
10 (control)	10.60	1.86a	10.6	1.86a
9	0.22	0.02d	0.19	0.02d
8	0.38	0.11c	0.21	0.008e
7	0.36	0.04d	0.24	0.008e
6	0.30	0.03d	0.44	0.09d
5	0.89	0.10c	1.47	0.22c
4	0.87	0.08c	1.22	0.18c
3	1.68	0.32b	4.99	0.87b
2	2.23	0.37b	4.22	0.74b
1	0.36	0.03d	1.73	0.24c

Note: Different letters indicate that values among blends and within species are significantly different at $P < 0.05$ (Duncan's multiple range test).

5 Conclusions and Recommendations

Conclusions

The results from the Phase 1 manufactured topsoil screening tests at ERDC, Vicksburg, MS, indicated that proprietary Blend 5 was best for plant growth of ryegrass. Blend 5 also looked very promising as a manufactured topsoil product and could be used in a beneficial manner. The results also showed that plant growth was enhanced by increasing the percentage of BIONSOIL™ biosolids in the blends. However, the quality of manufactured topsoil with respect to organic contaminant content will determine the end use of the soil product (Figure 9). Use of proprietary Blend 5 with untreated NY/NJ Harbor dredged material should be limited to cover for highly contaminated superfund sites, for abandoned mining sites, or for landfills, as shown in the upper right-hand corner of Figure 9.

Washing of the manufactured topsoil blends prepared with treated/decontaminated NY/NJ Harbor dredged material improved seed germination and plant growth. However, after factoring in the cost of leaching salt from the manufactured soil product and the cost of treating the NY/NJ Harbor dredged material, it would appear not to be economically feasible to use the treated/decontaminated NY/NJ Harbor dredged material unless the cost of treatment could be substantially reduced. Based on a patented formulation, proprietary Blend 5 containing untreated NY/NJ Harbor dredged material fortified with the appropriate amount of fertilizer has good potential for manufacturing topsoil from the NY/NJ Harbor Newton Creek Site.

Recommendations

It is recommended that proprietary Blend 5 containing untreated NY/NJ Harbor dredged material be demonstrated in a Phase 2 pilot-scale field study near the NY/NJ Harbor. A small-scale demonstration trial with the use of manufactured topsoil incorporating phytoremediation to manage

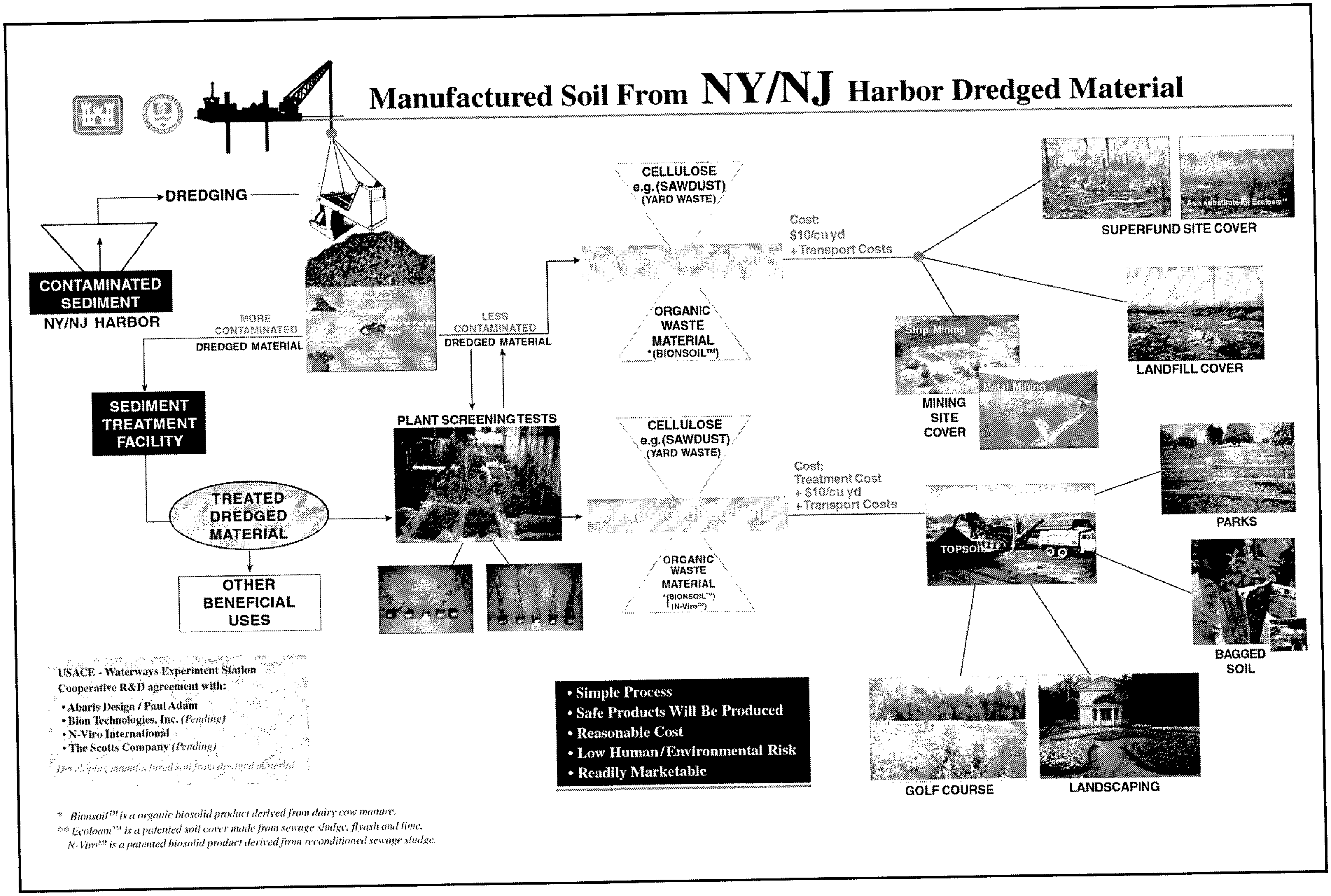

Figure 9. Diagram showing the process of manufacturing soil from NY/NJ Harbor dredged material and beneficial uses

contamination is recommended for Phase 2. However, if sufficient information is obtained from Phase 1 tests (bench-scale screening tests) a commercialization plan may be developed and additional phases may not be needed. Phase 3, a large-scale demonstration will provide necessary information on the economics of the manufactured topsoil technology including cost of materials, transport, and equipment prior to full-scale application of this technology. Following successful demonstrations, superfund, mining, and landfill sites should be considered for a Phase 3 large-scale application of proprietary Blend 5.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
October 2001

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Evaluation of Manufactured Soil Using Dredged Material from New York/ New Jersey Harbor Newton Creek Site
Phase 1: Greenhouse Bench-Scale Test

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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3909 Halls Ferry Road, Vicksburg, MS 39180-6199;
AScI Corporation, 1365 Beverly Road, McLean, VA 22101;
North Carolina State University, Raleigh, NC 27695-7619

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/EL TR-01-35

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, New York
Jacob K. Javits Federal Building 26 Federal Plaza, Room 2109
New York, NY 10278-0090

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Manufactured soil/beneficial reuse of dredged material is a potential strategy/alternative for long-term confined disposal. The development of a manufactured topsoil product will allow the U.S. Army Corps of Engineers to remove dredged material from confined disposal facilities (CDFs). This will increase the capacity of the CDFs and eliminate the shortage of CDFs for dredged material storage. In addition, manufactured topsoil from dredged material will potentially result in a product that can be reused in ways that are beneficial to the environment. Manufactured soil can be used for topsoil, bagged soil, landscaping, superfund site cover, mining site cover, and landfill cover.

The U.S. Army Engineer Research and Development Center, Vicksburg, MS, has established Cooperative Research and Development Agreements to develop technology for the manufacture of topsoil using sediment/dredged material (decontaminated and contaminated), cellulose waste materials, and nutrient-rich organic waste materials. The recycled soil manufacturing technology (RSMT) allowed the development of fertile topsoil that could be used in a beneficial, productive, and environmentally sound manner. In addition, the RSMT will provide an alternative to conventional disposal of the nation's waste/resource material from the Metcalf and Eddy process (decontaminated New York/New Jersey Harbor dredged material via solvent extraction) and untreated dredged material collected directly from the New York/New Jersey Harbor Newton Creek Site. Screening tests included proprietary blends with a range of dredged material content, a range of cellulose, and animal derived biosolids.

15. SUBJECT TERMS

Biosolids	Confined disposal facilities	Dredged material	Recycled soil manufacturing technology
Cellulose	Contaminated sediment	Manufactured topsoil	Screening tests
	Decontaminated sediment	Plant growth	Seed germination

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		47	